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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

SUMMARY REPORT

REPORT NO: NAWCADPAX/SUM-2002/171

F/A-18E/F NACELLE SIMULATOR INPUT/OUTPUT BOUNDARY CONDITION FLOWS

by

Joseph Dolinar
David Hudgins
Dr. David Keyser, INS, Inc.

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14. ABSTRACT

These tests were conducted to determine the distribution of airflows, without fire, across the boundary of the fire test nacelle. As a check on the overall accuracy of these flow measurements, a mass balance was performed as well. These data provide the boundary conditions for the Computational Fluid Dynamics models of this nacelle simulator. The proportional distribution of air effluxes remained nearly constant throughout the range of inlet flows and, therefore, the actual mass flows are nearly proportional to the total inflow.

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EXECUTIVE SUMMARY

Test Objective: The reason for conducting these tests was to determine the distribution of airflows, without fire, across the boundary of the fire test nacelle. As a check on the overall accuracy of these flow measurements, a mass balance was performed as well. The application of these data was to provide the boundary conditions for the Computational Fluid Dynamic (CFD) and VULCAN models of this nacelle simulator to be done by Sandia National Laboratory.

Summary of Test Results: The proportional distribution of air effluxes remained nearly constant throughout the range of inlet flows and, therefore, the actual mass flows are nearly proportional to the total inflow. There were several surprising observations during the tests. The first was that there was no perceptible flow in or out of the bottom aft vent. The second was the rather large variation, proportionately speaking, in the steady-state pressures measured inside the nacelle, the range being greater than the mean. The third observation was a severe velocity profile across the top aft vent. Most of the flow was exiting from the port side of the diamond; the velocity out the starboard side was estimated at ~20% of that out the port side. The pitot rake apparatus was designed to observe an overall average of that efflux collected by the converging duct.

It was predicted that half the flow would exit from the top aft vent; in fact, closer to 2/3 the flow exited at that location. Consequently, the model predicted about 6.5% more flow leaving via the Balance Piston Valve and 8.5% more by the four AMAD vents in the front bulkhead.

Uncertainty Estimates: When comparing the calibrated model to the mean test results, given the flow, the mean nacelle pressures agree within $\pm$4.5%. If given the supply pressure, the total flow agrees within $\pm$2.3%.

In the mass balance calculations of the means, the difference between the inflow and the sum of all effluxes ranges from 0 to 1.11% in the worst case.

Conclusions: The conduct of these tests was definitely worthwhile. Even the simplified models of the flow required actual test data to “calibrate” the nacelle vents and the overall flow and mass balance for the nacelle simulator, and to observe the actual pressure and flow distribution at the boundaries of the nacelle. These data are even more important in the development of the CFD and VULCAN models, which are deliverables under this program.

The simplified model reported herein is adequate, en large, to predict the overall flow and average pressures for any future test conditions desired. The pressure distribution is difficult to predict inside the nacelle; perhaps this model could be developed further to predict these and the distribution of exit flows better, if required.

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ACKNOWLEDGEMENT

This research is part of the Department of Defense's Next Generation Fire Suppression Technology Program, funded by the DoD Strategic Environmental Research and Development Program.

INTRODUCTION

OBJECTIVE

The objective of these tests was to measure the air inflow and the distribution of effluxes from the several vents in the F/A-18E/F Nacelle Fire Simulator under ambient conditions without a fire. The purpose of these data was to provide the boundary conditions for the Computational Fluid Dynamic (CFD) and VULCAN analyses of this nacelle simulator being modeled by Sandia National Laboratory. Later, the fire predictions of these CFD models will be compared to fire tests conducted in the simulator.

DEVICE UNDER TEST

Figure 1 shows the fire test simulator. The air inlet source is seen in the lower left coming up into the bottom of the nacelle. There are two vents in the top: a diamond-shaped vent in the aft, and a balance piston round vent about 1/3 aft of the face. On the front face, there are four exit holes simulating connections from the nacelle to the Airframe Mounted Accessory Drive (AMAD) bay and other parts of the aircraft. These four holes are arrayed around the engine as shown in figure 2.

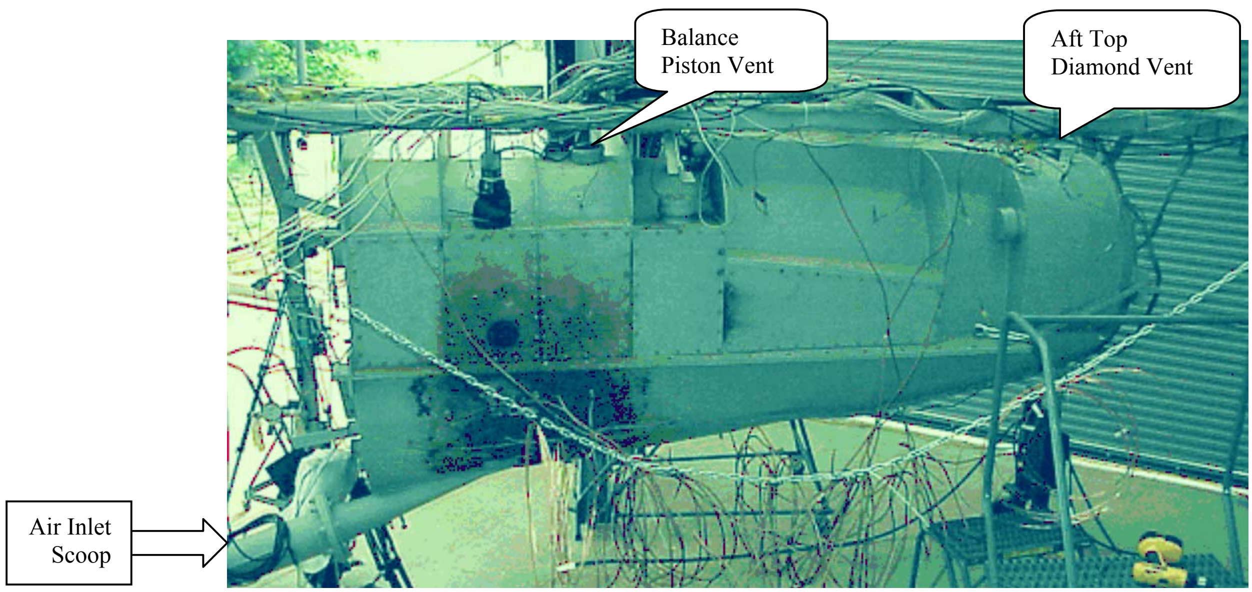

Figure 1: The F/A-18 Nacelle Ground Test Simulator, Port Side

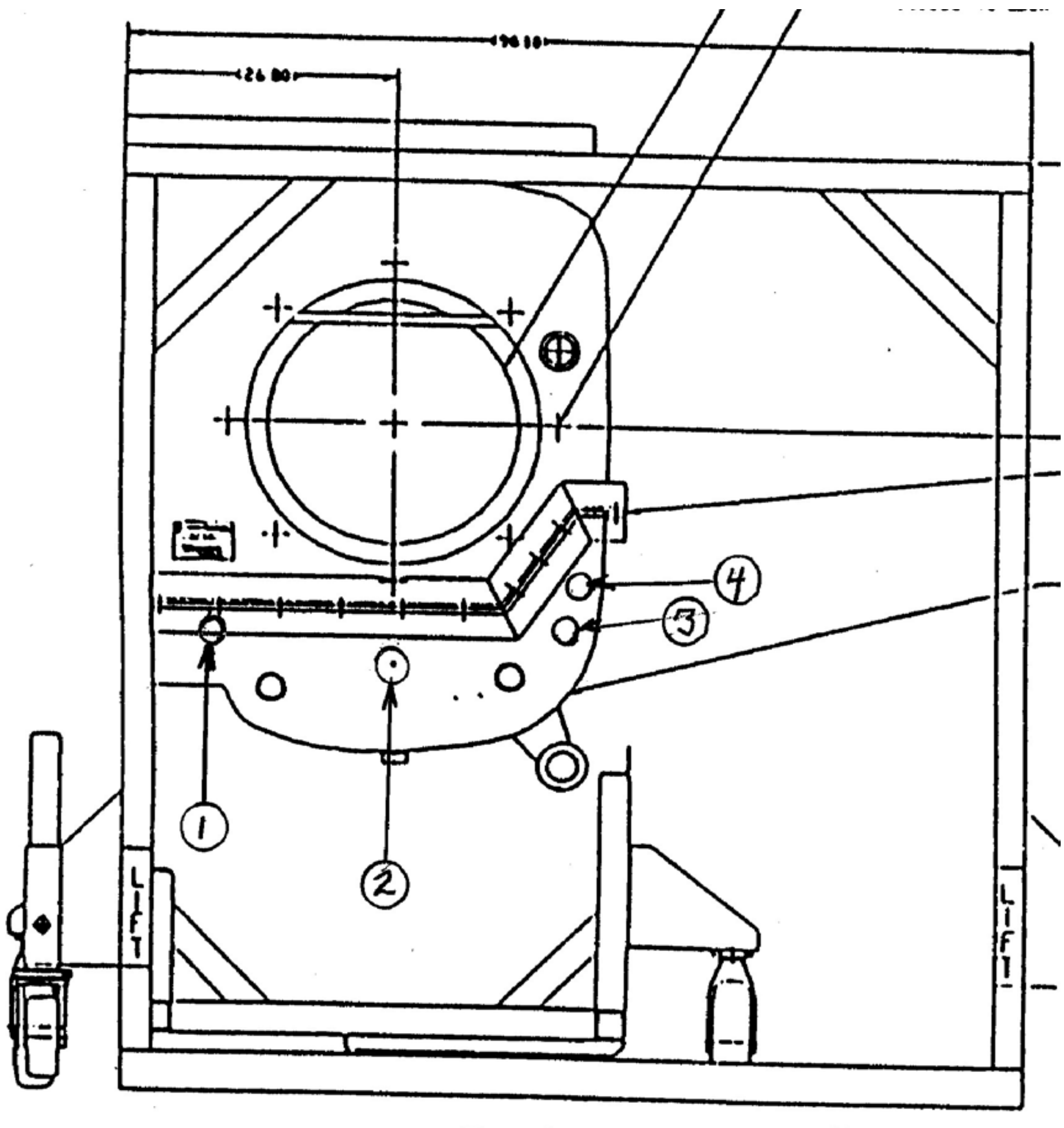

Figure 2: Front Face of the Nacelle Simulator

The hole dimensions are contained in table 1.

Table 1: Exit Hole Dimensions in the Front Face

Hole Number	i.d. (in.)
1	2.103
2	3.624
3	2.091
4	1.877

The flow areas of the top vents are: the diamond aft vent is 38.48 in.^{2}, and the balance piston vent is 3.54 in.^{2}.

BACKGROUND

In order to apply realistic boundary conditions to the CFD models being developed at Sandia, it was necessary to measure the inlet and outlet flows from the nacelle simulator under ambient conditions without fire. The openings shown in figures 1 and 2 are not the geometric ventilation paths. The various ventilation paths, such as the balance piston vent, aft diamond vents (both upper and lower), and AMAD bay ventilation paths in the front, have been "sized" to provide the flow distributions predicted in the airflow analysis conducted by Northrop-Grumman. Therefore, this simulator is designed for testing at one flight condition, traveling at 0.55M, sea level flight. Given this restriction, three nominal flows were selected to correspond to three major flight conditions: high-speed, high-altitude cruise, loiter, and precision approach (reference 1). These flows are 2.1, 1.5, and 1.25 lbm/sec, respectively, and were derived from flight tests of the F/A-18C/D, from which data were scaled up for the E/F aircraft.

The air is supplied from a centrifugal compressor which is driven by a gas turbine. The inlet flow is measured by a calibrated turbine meter. There is adequate straight pipe, according to ASME Standards (reference 2) and a flow straightener between the compressor and the turbine meter. Likewise, there is adequate straight pipe downstream of the turbine meter, and downstream of the 45-deg elbow, there is an Etoile swirl-removing conditioner in the straight pipe leading to the nacelle. The supply air pressure was measured with a water manometer immediately downstream of the turbine meter.

The air effluxes were measured at each of the outlets separately under steady state. The air temperatures in the nacelles were measured with thermocouples at four locations, one on each side and near each end of the nacelle. The airflow out the aft diamond vent was measured with a pitot rake. The airflow in the other outlets was measured with a calibrated vane anemometer and stopwatch. Air pressures in the nacelle were measured at three locations using an inclined water manometer.

All airflow data were corrected to ambient conditions at the time of test in order to determine the mass balance.

TEST METHOD

These were all steady state mass flow tests. The nominal mass flow of air was set on the control console by setting the speed of the gas turbine driving the blower. There was some small variation in flow, less than 6%, with a period of many seconds resulting from the gas turbine-mounted controls. During the test run at each rate, at least four readings were observed from each thermocouple and manometer. Considerably more data were observed from the turbine meter. The vane anemometer, which was used for all air efflux measurements except that from the aft diamond vent on top, was equipped with a mechanical totalizer. Consequently, a stopwatch was used to record the period of observation in order to obtain the average flow. The pitot rake and its converging ductwork came equipped with an electronic data output of its own,

and the readout that was selected was that of volumetric flow at atmospheric conditions. Its period of observation was about 1 min, and two such observations were recorded for each test condition.

All data were observed and recorded manually in view of the steady-state conditions. The automatic data acquisition system is designed for capturing transient fire events in the nacelle simulator and, therefore, would generate far more data than were required for this test. All data were averaged to provide a mean for each steady state. The observations could not be made simultaneously, and since there was some long-period variation in the flow, there results an additional uncertainty. The tests at each rate consumed about 20 to 25 min.

The original test data sheets are presented in Part 2 of appendix B.

INSTRUMENTATION

1. Supply Airflow Measurement: 6-in. Turbine Meter, Sponsler Co. Inc., Model SP6-CB-PH7-C-4X, S/N 130619, calibrated in water 3 January 2002.

2. Exit Airflow Measurement 4-in. Vane Anemometer, Taylor Instruments, Model 3132-A-4, S/N 2607, calibrated in air 24-25 April and 10 May 2002.

3. Exit Airflow Measurement: Pitot Rake Apparatus installed over the aft diamond vent on top of the nacelle. FLOWHOOD CFM-88 (with digital AirData Multimeter) by Shortridge Instruments, Inc. AirData Multimeter, Shortridge Instuments, Model No. ADM-870, S/N M98502, calibrated in air 3 July 1998.

4. Temperature Measurements: Four Type K thermocouples, uncalibrated, two mounted at F.S. 598.5, two at F.S. 703, each at 10:30 and 4:30 positions, looking forward.

5. Digital Stopwatch: Calibrated error less than 0.1 sec over 15-min period.

6. Exit Flow Tubes: Measured at four diameters (inch): Number 1 = 2.062, 2.043, 2.056, 2.042; Number 2 = 3.980, 3.939, 3.998, 3.984; Number 3 = 3.037, 3.051, 3.040, 3.055. These provided smooth one-dimensional flow to the vane anemometer.

7. ASME Pitot-Static Tube: o.d. .327 in.

The calibration data for the instrumentation is presented in appendix B; since the tests were conducted in 1 day, there were no posttest calibrations.

RESULTS

As aforementioned, the reason for conducting these tests was to determine the distribution of airflows, without fire, across the boundary of the fire test nacelle. As a check on the overall accuracy of these flow measurements, a mass balance was performed as well.

The proportional distribution of air effluxes remained nearly constant throughout the range of inlet flows and, therefore, the actual mass flows are nearly proportional to the total inflow. Table 2 summarizes these test results.

Table 2: Summary of Test Results of Flow Distribution

	Air Inflow (lbm/s)	Air Outlfows Aft Top	Air Outflows are All Shown as Ratios					Leaks
			BalPist	Stb. 2 in. Vent	Center 3.6 in. Vent	Port, Top Vent	Port, Bottom Vent	
Distribution of flow (ratio)	2.024	0.6651	0.0975	0.0260	0.1424	0.0199	0.0474	0.00127
	1.418	0.6397	0.0958	0.0263	0.1658	0.0234	0.0474	0.00122
	1.152	0.6442	0.0931	0.0264	0.1680	0.0196	0.0472	0.00123
Average	**Distr. %**	64.973	9.5526	2.6275	15.879	2.1024	4.7395	0.12442

As can be seen, there were air leaks, but their cumulative effect was less than 1.3% of the total flow. The detailed results of the data reduction for each of the three rates are shown in tables 3, 4, and 5.

Table 3: Test Data for the Input Flow of 2.02 lb/sec

2002	**Fire Sim Facility, Cold Flow Boundary Conditions**												
Test #:	1	Field Reports		59.7	deg F	Dew Point	34	Wind	N 13	kts	Nom Flow=	2.1	lbm/sec
Date:	21-May	Dry Bulb	55		deg F	Barometer	30.32	RH=46%	VP. inHg=	0.432	Actual Fl=	2.0249318	lbm/sec
Time:	1115-40	Wet Bulb	45.5	Hole>1	2	3	4	Inclined	Inclined	Inclined	Inclined	P supply	ASM Epitot
AirInflow	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Manometer	Manometer	Manometer	Manometer	Manometer	Manometer
Turbine,	Aft Bott	Aft Top	BalPist	Stb. 2" vent	Center 3.6"v	Port, top Ve	Port, Bottor	No. 2	No. 2	No. 2	No. 2	No. 4	portable
Volts	Anemom	Pitot Rake	Anemom	Anemom	Anemom	Anemom	Anemom	in H2O	in H2O	in H2O	in H2O	in H20	mmH2O
	0	cfm	fps	fps				fs598por7	fs598stb	fs690port	fs690stb		12
5.63		1097.30	30.80		fps			2.55	0.84	1.32	1.36	20.50	13.00
5.62		vel profile:		31.27		fps		2.57	0.79		1.37	19.90	12.00
5.44		stb half=			48.32		fps	2.57					
5.39		7.42				28.59		2.82					3 tare
5.42		port half=					25.80	**2.63**	**0.81**	**1.32**	**1.37**	**20.20**	**9.50**
5.50	<ave	32.44	**30.80**	**31.27**	**48.32**	**28.59**	**25.80**						
			cfs	cfs	cfs	cfs	cfs						
0.30	U 95%	cfs						Leaks					
Efflux, tot	**27.71**	18.29	2.68	0.72	4.14	0.55	1.31	0.04					
Distributic	**ratio**	0.66	0.10	0.03	0.15	0.02	0.05	0.00					
Influx, tot	**28.03**	+/-	1.50						T 1	T 15	T 17	T 31	
	1.01								deg F	deg F	deg F	deg F	
					&from Pitot Flow Tube:								
Density of flowing air:		0.07	lbm/cu.ft.		3.56	cfs							
									87.50	88.60	87.00	84.90	
					12.81	is expected dP of Pitot, mm H20			88.90	87.90	87.60	88.00	
Notes:____________________________________													Ave.
Hole id,in.		area, sqft							**88.20**	**88.25**	**87.30**	**86.45**	**87.55**
#1	2.10	0.02					There is a big difference in the flow profile						
#2	3.62	0.07					exiting from the upper aft diamond vent!						
#3	1.88	0.02											
#4	2.09	0.02	0.14				micromanometer zero = 3 mm						
FlowTube id, in.		0.00											
#1	2.05	0.02					Leak at fs690stb=		9.69	fps			
#2	3.98	0.09	**0.09**	flow area			thru	0.00	sqft =	0.02			
#3	3.05	0.05					at aft end	2.77	x.00342=	0.02	est		
Pitot tube	0.33	0.00					glass	2.47	.>	0.00	est		
Bal Piston	4.00	0.09	*					**Total**	**Leaks**	0.04			
			26.43	sq. in. tot.									

Table 4: Test Data for the Input Flow of 1.42 lb/sec

2002.00	**Fire Sim Facility, Cold Flow Boundary Conditions**												
Test #:	2.00	Field Reports		58.60	deg F	Dew Point	36.00	Wind	Vrbl 5	kts	Nom Flow=	1.50	lbm/sec
Date:	37397.00	Dry Bulb	55.00		deg F	Barometer	30.31	RH=49%	VP. inHg=	0.43	Actual Fl=	1.42	lbm/sec
Time:	1300-20	Wet Bulb	46.00	Hole>1	2.00	3.00	4.00	Inclined	Inclined	Inclined	Inclined	P supply	ASM Epitot
AirInflow	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Manometer	Manometer	Manometer	Manometer	Manometer	Manometer
Turbine, V.	Aft Bott	Aft Top	BalPist	Stb. 2" vent	Center 3.6"v	Port, top Ve	Port, Bottor	No. 2	No. 2	No. 2	No. 2	No. 4	portable
3.98	Anemom	Pitot Rake	Anemom	Anemom	Anemom	Anemom	Anemom	in H2O	in H2O	in H2O	in H2O	in H20	mmH2O
4.00	0.00	cfm	fps	fps				fs598port	fs598stb	fs690port	fs690stb	4.80	8.50
4.01		730.40	21.45		fps					0.62		4.30	
3.92		765.10		22.34		fps		0.40	1.21		0.69	4.90	
3.87					39.87		fps					4.30	
3.89						23.79							3 tare
4.00							18.26	**0.40**	**1.21**	**0.62**	**0.69**	**4.50**	**5.50**
3.99	<ave		**21.45**	**22.34**	**39.87**	**23.79**	**18.26**						
3.96			cfs	cfs	cfs	cfs	cfs						
0.62	U95%	cfs						Leaks					
Efflux, tot	**19.48**	12.46	1.87	0.51	3.23	0.46	0.92	0.02					
	ratio	0.64	0.10	0.03	0.17	0.02	0.05	0.00					
									T 1	T 15	T 17	T 31	
Influx, tot	**19.44**	average	+/-	0.62	U95%				deg,F	deg,F	deg,F	deg,F	
	1.00												
					&from Pitot Flow Tube:				78.90	79.60	74.80	81.90	
Density of flowing air:		0.07	lbm/cu.ft.		2.69	cfs			80.90	81.50	78.30	84.30	
									80.80	81.60	80.20	83.40	
					7.96	is expected dP for Pitot, mm H20					80.50		
													Ave.
									80.85	**81.55**	**79.67**	**83.85**	**81.48**
			0.00										
							There is a big difference in the flow profile						
	fps	area, sqft					exiting from the upper aft diamond vent!						
#1	2.10	0.02											
#2	3.62	0.07					micromanometer zero = 3 mm						
#3	1.88	0.02											
#4	2.09	0.02	55.62	tot.area, sq. in.			Leak at fs690stb=		6.53	fps			
FlowTube id, in.		0.00					thru	0.00	sqft =	0.01			
#1	2.05	0.02					at aft end	2.98	x.00342=	0.01			
#2	3.98	0.09	**0.08**	flow area			glass	3.64	.>	0.00			
#3	3.05	0.05	*						**Leaks, tot**	0.02			
Pitot tube	0.33	0.00											
Bal Piston	4.00	0.09											

Table 5: Test Data for the Input Flow of 1.15 lbm/sec

2002.00	**Fire Sim Facility, Cold Flow Boundary Conditions**												
Test #:	3.00	Field Reports		58.60	deg F	Dew Point	37.00	Wind	E 8	kts	Nom Flow=	1.20	lbm/sec
Date:	37397.00	Dry Bulb	57.00		deg F	Barometer	30.28	RH=48%	VP. inHg=	0.47	Actual Fl=	1.15	lbm/sec
Time:	1330-50	Wet Bulb	47.50	Hole>1	2.00	3.00	4.00	Inclined	Inclined	Inclined	Inclined	P supply	ASM Epitot
AirInflow	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Manometer	Manometer	Manometer	Manometer	Manometer	Manometer
Turbine,	Aft Bott	Aft Top	BalPist	Stb. 2" vent	Center 3.6"v	Port, top Ve	Port, Bottor	No. 2	No. 2	No. 2	No. 2	No. 4	portable
Volts	Anemom	Pitot Rake	Anemom	Anemom	Anemom	Anemom	Anemom	in H2O	in H2O	in H2O	in H2O	in H20	mmH2O
	0.00	cfm	fps	fps				fs598port	fs598stb	fs690port	fs690stb	3.30	too low
3.30		612.60	16.94		fps					0.43	0.44	3.30	
3.30				18.25		fps		0.79	0.25		0.44	3.30	
3.29					32.86		fps					3.30	
3.26						16.18							3 tare
3.27							14.80	**0.79**	**0.25**	**0.43**	**0.44**	**3.30**	
3.29	<ave		**16.94**	**18.25**	**32.86**	**16.18**	**14.80**						
			cfs	cfs	cfs	cfs	cfs						
0.22	U 95%	cfs						Leaks					
Efflux, tot	**15.85**	10.21	1.48	0.42	2.66	0.31	0.75	0.02					
	ratio	0.64	0.09	0.03	0.17	0.02	0.05	0.00					
Influx, tot	**15.85**	average	+/-	0.23					T 1	T 15	T 17	T 31	
	1.00								deg F	deg F	deg F	deg F	
3.21					&from Pitot Flow Tube:								
3.18		586.90			#VALUE!	cfs			82.30	82.40	80.90	85.30	
3.19		9.78							82.60	83.60	81.90	86.40	
3.17		0.63							82.60	83.30	81.80	86.60	
	fps	Density of Flowing Air:		0.07	lbm/cu.ft.				82.40	83.50	82.00	86.60	
3.19	<ave												Ave.
Influx, tot	15.61	+/-	0.23						**82.53**	**83.47**	**81.90**	**86.53**	**83.61**
0.04	U 95%						There is a big difference in the flow profile						
	fps	area, sqft					exiting from the upper aft diamond vent!						
#1	2.10	0.02											
#2	3.62	0.07					micromanometer zero = 3 mm						
#3	1.88	0.02											
#4	2.09	0.02					Leak at fs690stb=		4.89	fps			
FlowTube id, in.		0.00					thru	0.00	sqft =	0.01			
#1	2.05	0.02					at aft end	2.77	x.00342=	0.01			
#2	3.98	0.09	**0.08**	flow area			glass	2.47	.>	0.00			
#3	3.05	0.05	*						**Leaks, tot**	0.02			
Pitot tube	0.33	0.00											
Bal Piston	4.00	0.09											

There were several surprising observations during the tests. The first was that there was no perceptible flow in or out of the bottom aft vent. It could be that the very fine mesh screen (~128/in.) which covered this vent was clogged with soot and rust particles—or that the flow pattern inside the nacelle was directed away from this vent by the interior ribs.

The second was the rather large variation, proportionately speaking, in the average pressures measured inside the nacelle, the range being greater than the mean.

The third observation was a severe velocity profile across the top aft vent. Most of the flow was exiting from the port side of the diamond; the velocity out the starboard side was measured with the vane anemometer to be ~20% of that out the port side. The pitot rake apparatus was designed to observe an overall average of that efflux collected by the converging duct.

Comparison with the Pretest Model. The only corrections made to the pretest model were the fact of no flow from the aft bottom vent was incorporated, and the actual, measured vent areas were used instead of their previous estimates. In retrospect, the only assumption which had any consequence was that of a uniform pressure throughout the interior of the nacelle simulator. As mentioned above, these large variations were unexpected, and they contributed significantly to the differences between the actual flow distribution at the boundaries and those predicted. These results, for all test conditions, are summarized in table 6.

Table 6: Predicted Flow Distribution Out the Vents

Inflow	Top Exit Flow	BPV Flow	AMAD Flow	Distribution			
(Lbm/s)	(Lbm/s)	(Lbm/s)	(Lbm/s)	(%)	(%)	(%)	**Sum =**
2.0249	1.0054	0.3273	0.6905	49.65	16.16	34.103	99.91
1.4189	0.7045	0.2293	0.4839	49.65	16.16	34.103	99.91
1.1525	0.5722	0.1863	0.3930	49.65	16.16	34.103	99.91

It was predicted that half the flow would exit from the top aft vent. In fact, closer to 2/3 the flow exited at that location. Consequently, the model predicted about 6.5% more flow leaving via the Balance Piston Valve and 8.5% more by the four AMAD vents in the front bulkhead. The test predictions of the model as adjusted for the actual vent areas are shown in table 7.

Table 7: Comparison of Predicted versus Measured Pressures and Flows

Inflow (Lbm/s)	Predicted Pitot Press in H_2O	Measured Pitot Press in H_2O	Meas. Ave. Nac. Pr. In. H_2O	Predicted Nac. Pr. In. H_2O	Bias ratio
2.0249	0.5835	0.374	1.530	1.529	-0.00041
1.4189	0.2869	0.216	0.730	0.753	0.03151
1.1525	0.1894	too small	0.475	0.497	0.04570

In discussing the agreement between model and test in the total flow and average pressures, it is a fact that the test was a calibration of the nacelle simulator. In constructing the model, it was assumed that the balance piston vent and aft top vent would behave as parallel orifices and that the AMAD vents would behave more like nozzles. A weighted average of these coefficients of discharge was predicted to be 0.733. By actual test and calibration, it was determined that the effective coefficient of discharge equals 0.614. This value implies that all the vents behave essentially as sharp-edged orifices. This value of the coefficient of discharge correlates very well

with the published data for the vent Reynolds number range, during test, of 1680 to 6800 for which the coefficient is 0.613 to 0.605, respectively (reference 3).

Uncertainty Estimates. When comparing the calibrated model to the mean test results, given the flow, the mean nacelle pressures agree within ±4.5%. If given the supply pressure, the total flow agrees within ±2.3%.

In the mass balance calculations of the means, the difference between the inflow and the sum of all effluxes ranges from 0 to 1.11% in the worst case. In both of the above cases, the "law of averages" comes into play.

The component uncertainties in the measurements are much larger:

The dominant component of the turbine meter's inflow measurement is the unsteadiness of the flow during the test, which contributes ±1.4%, 3.2%, and 5.3% random uncertainty in the inflow measurement at 95% confidence. The manufacturer, who calibrated this instrument, claims a calibration uncertainty of ±0.22%, though we believe it to be closer to 0.33%.

The anemometer calibration data manifest an uncertainty of ±2.6% over the range of the test flows; consequently, each vent flow measured with this instrument has at least this uncertainty at the 95% confidence level.

The pitot rake apparatus is uncalibrated, but it was "zeroed" before each test run. Its uncertainty is undetermined, but it is likely less than 5%. The manufacturer advertises an uncertainty of ±3%.

The thermocouples are likewise uncalibrated. However, the sensitivity of the test results to these measurements is so small that the contribution of this component of uncertainty is negligible.

The digital voltmeter is calibrated yearly, and likewise its contribution to the overall test uncertainty is negligible.

CONCLUSIONS AND RECOMMENDATIONS

The conduct of these tests was definitely worthwhile. Even the simplified models of the flow required actual test data to "calibrate" the nacelle vents and the overall flow and mass balance for the nacelle simulator, and to observe the actual pressure and flow distribution at the boundaries of the nacelle. These data are even more important in the development of the CFD and VULCAN models, which are deliverables under the NGP 6A program.

The simplified model reported herein is adequate, en large, to predict the overall flow and average pressures for any future test conditions desired. The pressure distribution is difficult to predict inside the nacelle; perhaps this model could be developed further to predict these and the distribution of exit flows better, if required.

The uncertainties of the test data and results met the pretest expectations and fulfill the objectives of the tests.

REFERENCES

1. Northrop-Grumman Report, F/A-18E/F Engine Bay Flow and Temperatures, NOR-98-303, of 1 Jul 1998.

2. ASME Performance Test Code, Interim Supplement 19.5 on Flow Measurement, 6th Edition, 1971.

3. Fluid Meters, Their Theory and Application, 5th Edition, 1959, ASME, Table 15.

APPENDIX A
TEST INFORMATION AND TEAM MEMBERS

Date and Time of Test: 21 May 2002, 1130 - 1345
Location of Test: Bldg. 2244, NAS Patuxent River, Maryland

Equipment Owner: NAVAIR (4.3.5.1)
Equipment Identification: F/A-18 Ground Test Fire Simulator
Parties Conducting Test: NAVAIR: Messrs. J. Dolinar, D. Hudgins, B. Myers
INS, Inc.: Dr. David Keyser
Parties Responsible for Test Report: INS, Inc.

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APPENDIX B
INSTRUMENT CALIBRATION AND TEST DATA

Table B-1: Ambient Weather Conditions during Testing

Date	Time (edt)	Wind (mph)	Vis. (mi.)	Weather	Sky Condition	Temperature (ºF)				Pressure		Precipitation		
						Air	Dwpt	6 hr		altimeter (in.)	sea level (mb)	1 hr	3 hr	6 hr
								Max.	Min.					
22	11:55	NE 8	7.00	Partly Cloudy	SCT040	61	33			30.40	1029.3			
22	10:55	Vrbl 6	7.00	Partly Cloudy	SCT040	60	35			30.41	1029.7			
22	09:55	N 10	7.00	A Few Clouds	FEW040	59	38			30.39	1029.2			
22	08:55	NE 12	7.00	Clear	SKC	57	40			30.39	1029.1			
22	07:55	Calm	7.00	Clear	SKC	51	39	51	39	30.37	1028.4			
22	06:55	N 8	7.00	Clear	SKC	49	36			30.36	1028.2			
22	05:55	N 7	7.00	A Few Clouds	FEW080 FEW200	45	36			30.35	1027.8			
22	04:55	N 10	7.00	A Few Clouds	FEW200	47	33			30.33	1027.2			
22	03:55	NW 6	7.00	A Few Clouds	FEW080 FEW200	43	37			30.33	1027.1			
22	03:28	NW 5	7.00	A Few Clouds	FEW080	41	36			30.34	1027.3			
21	23:55	S 5	7.00	A Few Clouds	FEW080	41	36			30.33	1027.1			
21	22:55	W 5	7.00	A Few Clouds	FEW080	43	36			30.33	1027.1			
21	21:55	W 3	7.00	A Few Clouds	FEW080	46	37			30.32	1026.7			
21	20:55	N 8	7.00	A Few Clouds	FEW080	52	32			30.30	1026.0			
21	19:55	NW 8	7.00	A Few Clouds	FEW080	54	30	60	54	30.29	1025.8			
21	18:55	N 12	7.00	Partly Cloudy	SCT080	57	30			30.28	1025.3			
21	17:55	N 16 G 20	7.00	Partly Cloudy	SCT080	58	30			30.27	1024.9			
21	16:55	NW 12	7.00	Partly Cloudy	SCT080	60	32			30.27	1025.0			
21	15:55	N 14	7.00	Mostly Cloudy	FEW040 SCT070 BKN200	59	32			30.27	1002.5			
21	14:55	NW 9	7.00	Mostly Cloudy	SCT040 SCT080 BKN200	58	33			30.28	1025.4			
21	13:55	E 8	7.00	Mostly Cloudy	SCT040 SCT080 BKN200	57	37	57	52	30.28	1025.5			

Date	Time (edt)	Wind (mph)	Vis. (mi.)	Weather	Sky Condition	Temperature (ºF)				Pressure		Precipitation		
						Air	Dwpt	6 hr		altimeter (in.)	sea level (mb)	1 hr	3 hr	6 hr
								Max.	Min.					
21	12:55	Vrbl 5	7.00	Mostly Cloudy	SCT040 BKN200	55	36			30.31	1026.2			
21	11:55	N 13	7.00	Mostly Cloudy	SCT040 SCT060 BKN200	55	34			30.32	1026.6			
21	10:55	NE 13	7.00	Mostly Cloudy	SCT040 BKN200	54	37			30.32	1026.7			
21	09:55	NE 12	7.00	Mostly Cloudy	FEW030 SCT060 BKN100	54	42			30.32	1026.5			
21	08:55	NE 10	7.00	Partly Cloudy	FEW030 SCT060 SCT100	52	40			30.31	1026.2			
21	07:55	NE 9	7.00	Partly Cloudy	FEW030 SCT100	51	39	51	47	30.26	1025.7			
21	06:55	N 3	7.00	Partly Cloudy	SCT100	48	41			30.27	1025.0			
21	05:55	N 8	7.00	A Few Clouds	FEW100	47	40			30.24	1024.0			
21	04:55	N 6	7.00	Partly Cloudy	FEW060 SCT100	48	39			30.22	1023.5			
21	03:55	N 8	7.00	Mostly Cloudy	FEW060 BKN100	50	39			30.21	1023.0			
21	02:55	N 6	7.00	Mostly Cloudy	FEW060 BKN100	50	37			30.22	1023.2			
21	01:55	N 9	7.00	Partly Cloudy	FEW060 SCT100	52	36	52	45	30.22	1023.2			
21	00:55	N 9	7.00	Partly Cloudy	FEW060 SCT100	52	34			30.22	1023.3			
20	23:55	N 8	7.00	Mostly Cloudy	BKN100	52	33			30.22	1023.3			
20	22:55	N 8	7.00	Mostly Cloudy	FEW060 BKN100	52	36			30.21	1023.1			

Table B-2: Turbine Meter Calibration in Water

Turbine Meter Calibration
Model SP6-CB-PH7-C-4X, S/N 130619

Sponsler Co.
2363 Sandifer Rd
Westminster, S.C. 29693

Calibrated in water; 500 lbm pumped through in time interval, measured. 8.0267 cf at 60.9F
<------- Published Data Report----------->

Volume (ft^3)	Time (sec)	SCFM	"K"	cf/s	SCFM Derived	Error	Signal out (VDC)	Cf/s
8.0267	0.165	2914.931	8.1	48.64667	2918.8	-0.00133	10.01304	48.64667
8.0267	0.2	2413.165	8.22	40.1335	2408.01	0.002136	8.260755	40.1335
8.0267	0.222	2173.012	8.1	36.15631	2169.378	0.001672	7.442122	36.15631
8.0267	0.27	1783.591	8.22	29.72852	1783.711	-6.7E-05	6.119078	29.72852
8.0267	0.317	1520.192	8.1	25.32082	1519.249	0.00062	5.211833	25.32082
8.0267	0.367	1312.515	8.22	21.87112	1312.267	0.000189	4.501774	21.87112
8.0267	0.413	1167.106	8.22	19.43511	1166.107	0.000856	4.000366	19.43511
8.0267	0.606	795.157	8.22	13.24538	794.7228	0.000546	2.726322	13.24538
8.0267	0.863	558.063	8.22	9.300927	558.0556	1.32E-05	1.914428	9.300927
8.0267	1.934	249.005	8.22	4.15031	249.0186	-5.5E-05	0.854266	4.15031
8.0267								

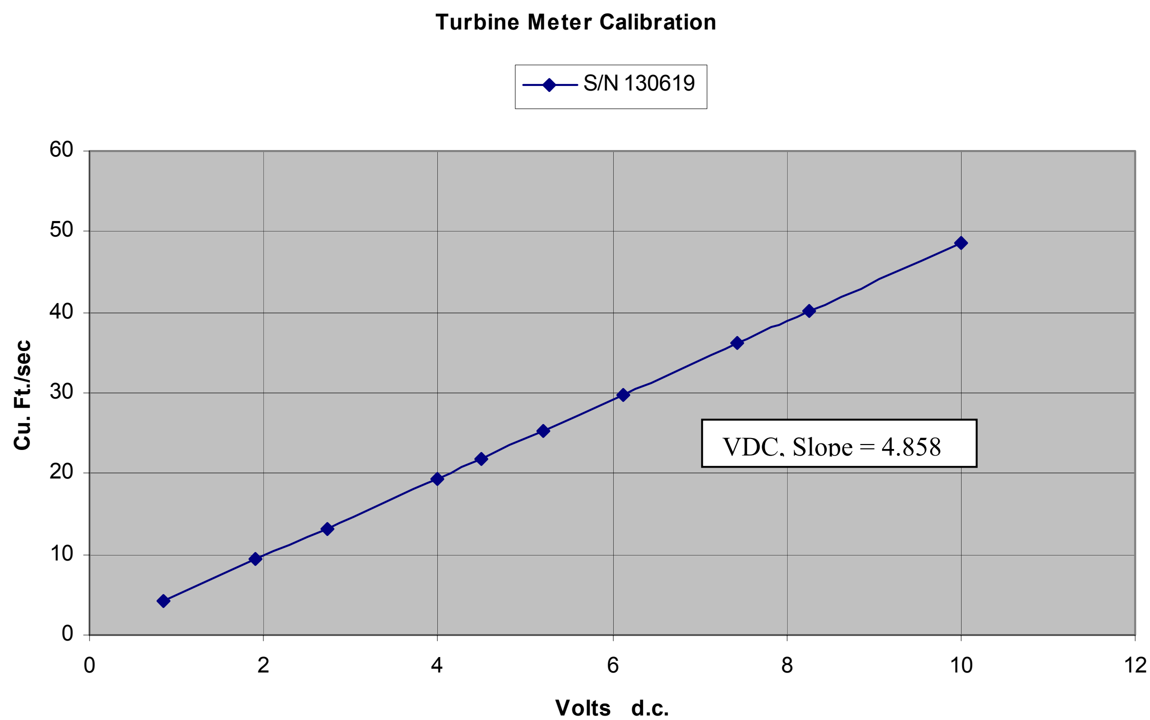
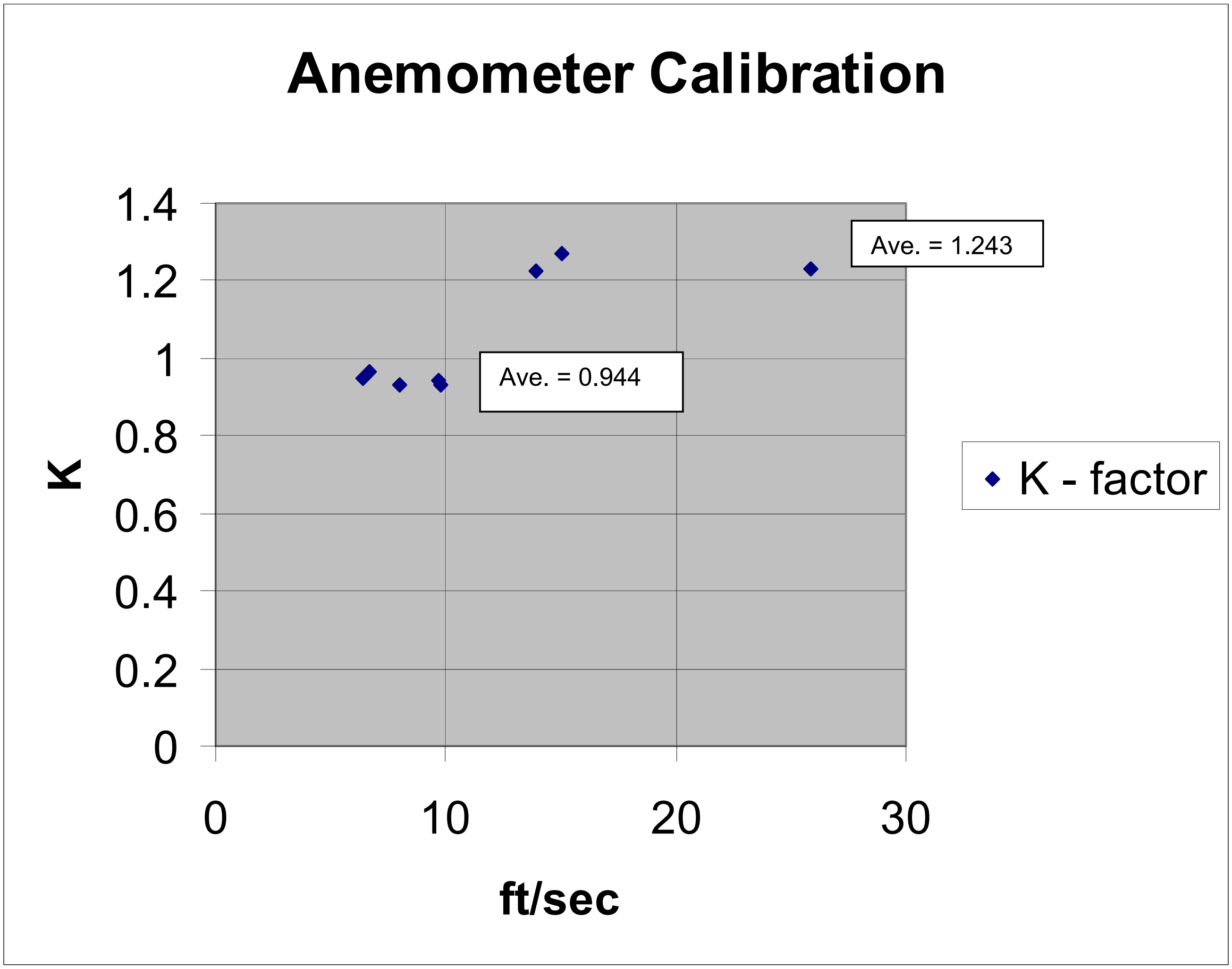
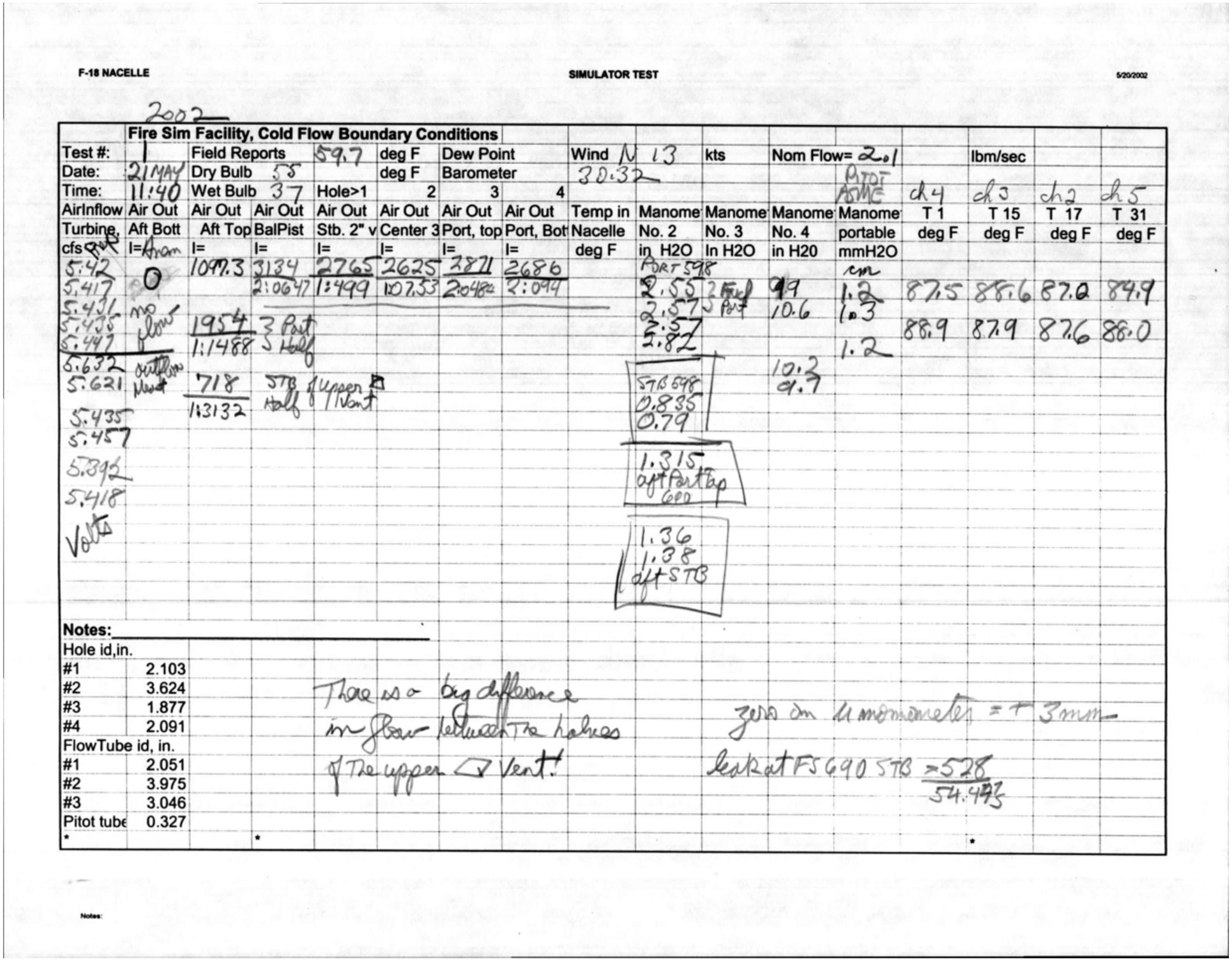


Table B-3: Anemometer Calibration in Air

Anemometer Calibration									
Date:	24-Apr	2002							
AMAD vel		El. Time	Anemom	Distance	Distance	El Time	Cal Vel	Anem Kf	Correction
ft/s	mph	m:s	reading. Ft	mile	ft	sec	ft/sec	ft/sec	Factor
65.4832	44.64644								
62.39237	42.53912								
59.29756	40.42907								
56.19895	38.31644								
53.09674	36.20136								
49.99113	34.08395								
46.8823	31.96435		Stopwatch Calibration: < 0.1 sec slow over 15 minutes						
43.77046	29.8427								
40.65581	27.71913								
37.53854	25.59378								
34.41885	20east	02:02.6	4110	0.75	3960	122.6	32.30016	33.52365	
31.29695	20west	02:06.2	2292	0.75	3960	126.2	31.37876	18.16165	
28.17302	19.20836			0.75	3960	Average	31.83946	25.84265	1.232051
	10east	04:41.8	4323	0.75	3960	281.8	14.05252	15.34067	
	10west	03:45.0	1781	0.75	3960	225	17.6	7.915556	
	10east	3:30	5109	0.75	3960	210	18.85714	24.32857	
						Average	17.02742	13.87509	1.227193
				ft					#DIV/0!
Date:	25-Apr		129	still air	120	16.2	7.407407	7.962963	0.930233
			124.5		120	18.7	6.417112	6.657754	0.963855
			126.5		120	19.9	6.030151	6.356784	0.948617
			128.5		120	13.2	9.090909	9.734848	0.933852
			127		120	13.1	9.160305	9.694656	0.944882
								25.84265	1.232051
								13.87509	1.227193
Date:	10-May	wind mostly N7 to NW6 kts; maybe <=NE 12 , last data							
	6 west	07:18.6	3137		3960	438.6	9.028728		
	6 east	07:25.0	2602		3960	445	8.898876	6.49502	1.370281
	12 west	03:44.2	3337		3960	224.2	17.6628		
	12 east	03:53.3	3540		3960	233.3	16.97385	15.03169	1.268653
*	15 west	03:07.0	3660		3960	187	21.17647		
	15 east	02:45.0	3322		3960	165	24	19.83523	1.138379
								6.356784	0.948617
								6.657754	0.963855
								7.962963	0.930233
								9.694656	0.944882
								9.734848	0.933852
								13.87509	1.227193


Anemometer Calibration
1.4
1.2
1
0.8
0.6
0.4
0.2
0
K
Ave. = 1.243
Ave. = 0.944
K - factor
0
10
20
30
ft/sec

Original data sheets from tests follow:



F-18 NACELLE SIMULATOR TEST 5/20/2002

2002

Fire Sim Facility, Cold Flow Boundary Conditions																
Test #:	1	Field Reports	59.7	deg F	Dew Point			Wind	N 13	kts	Nom Flow= 2.01			lbm/sec		
Date:	21 MAY	Dry Bulb	55	deg F	Barometer			30.32								
Time:	11:40	Wet Bulb	37	Hole>1	2	3	4					PITOT ASME	ch4	ch3	ch2	ch5
AirInflow	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Temp in	Manome	Manome	Manome	Manome	T 1	T 15	T 17	T 31
Turbine,	Aft Bott	Aft Top	BalPist	Stb. 2" v	Center 3	Port, top	Port, Bot	Nacelle	No. 2	No. 3	No. 4	portable	deg F	deg F	deg F	deg F
cfs Port	I= Amm	I=	I=	I=	I=	I=	I=	deg F	in H2O	In H2O	in H20	mmH2O				
5.42	0	1097.3	3134	2765	2625	2871	2686		PORT 598			cm				
5.417			2:0647	1:499	107.53	2:048	2:044		2.55	2 Fwd	9.9	1.2	87.5	88.6	87.0	84.9
5.431	no								2.57	3 Port	10.6	1.3	88.9	87.9	87.6	86.0
5.435	flow	1954	3 Port						2.57							
5.447		1:1488	3 Half						2.82			1.2				
5.632	outflow										10.2					
5.621	Vent	718	STB Half	Upper Vent					STB 598		9.7					
		1:3132							0.835							
5.435									0.79							
5.457									1.315 aft Port top 600							
5.392																
5.418									1.36							
Volts									1.38 aft STB							

Notes:

Hole id,in.	
#1	2.103
#2	3.624
#3	1.877
#4	2.091
FlowTube id, in.	
#1	2.051
#2	3.975
#3	3.046
Pitot tube	0.327

There is a big difference in flow between the halves of the upper Vent!

zero on u manometer = + 3mm

leak at FS 690 STB = 528
54.473 [illegible]

Notes:

F-18 NACELLE SIMULATOR TEST 5/20/2002

2002

	Fire Sim Facility, Cold Flow Boundary Conditions															
Test #:	1	Field Reports		59.7	deg F	Dew Point		Wind	N 13	kts	Nom Flow=	2.01		lbm/sec		
Date:	21 MAY	Dry Bulb	55		deg F	Barometer		30.32								
Time:	11:40	Wet Bulb	37	Hole>1	2	3	4					PITOT ASME	ch4	ch3	ch2	ch5
AirInflow	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Temp in	Manome	Manome	Manome	Manome	T 1	T 15	T 17	T 31
Turbine,	Aft Bott	Aft Top	BalPist	Stb. 2" v	Center 3	Port, top	Port, Bot	Nacelle	No. 2	No. 3	No. 4	portable	deg F	deg F	deg F	deg F
cfs	I=Anom	I=	I=	I=	I=	I=	I=	deg F	in H2O	In H2O	in H2O	mmH2O				
5.42	0	1097.3	3134	2765	2625	2871	2686		PORT 598			cm				
5.417			2:0647	1:499	107.53	2:0482	2:094		2.55	2 Fwd	9.9	1.2	87.5	88.6	87.0	84.9
5.431 no									2.57	3 Port	10.6	1.3				
5.435 flow		1954	3 Port						2.57				88.9	87.9	87.6	88.0
5.447		1:1488	5 Half						2.82			1.2				
5.632 outflow											10.2					
5.621 Nest		718	STB Half	f upper ▽ Vent					STB 598		9.7					
5.435		1:3132							0.835							
5.457									0.79							
5.392									1.315 aft Port Tap 600							
5.418									1.36							
Volts									1.38 aft STB							

Notes:

Hole id,in.	
#1	2.103
#2	3.624
#3	1.877
#4	2.091
FlowTube id, in.	
#1	2.051
#2	3.975
#3	3.046
Pitot tube	0.327
*	

There is a big difference in flow between the holes of the upper ▽ Vent!

zero on U monometer = + 3mm

leak at FS 690 STB = 528

54.493

Notes:

F-18 NACELLE SIMULATOR TEST 8/20/2002

	Fire Sim Facility, Cold Flow Boundary Conditions																
Test #:	3	Field Reports		58.6	deg F	Dew Point		Wind		kts	Nom Flow=		1.26	lbm/sec			
Date:	DIMS	Dry Bulb			deg F	Barometer											
Time:	1330-	Wet Bulb		Hole>1	2	3	4						4	3	2	5	
Airinflow	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Air Out	Temp in	Manome	Manome	Manome	Manome	T 1	T 15	T 17	T 31	
Turbine,	Aft Bott	Aft Top	BalPist	Stb. 2" v	Center 3	Port, top	Port, Bot	Nacelle	No. 2	No. 3	No. 4	portable	deg F	deg F	deg F	deg F	
V	I=	I=CPM	I=	I=	I=	I=	I=	deg F	in H2O	In H2O	in H20	mmH2O					
3301																	
		612.6		2224		2047			Aft Port		3.3		82.3	82.4	80.9	85.3	
3.303				2:3150		2:3722			.425		3.3						
													82.6	83.6	81.9	86.4	A
3.289			2181		2564				Aft Std		3.3						
			2:4000		1:370		2047		.435		3.3		82.6	83.3	81.8	86.6	57.4
3.262							2:5191		.44								
3.272									FWD Port				82.4	83.5	82.0	86.6	57.8
									.79								
End of test																	
3.211		5869							FWD Std								
3.182									.25								
3.186																	
3.173																	
3.167																	

Notes:

Hole id,in.	
#1	2.103
#2	3.624
#3	1.877
#4	2.091
FlowTube id, in.	
#1	2.051
#2	3.975
#3	3.046
Pitot tube	0.327
*	

Used Anemometer & Stopwatch for all outflows, except aft Top Vent I used rake

Δ gap $\left(4'' \times .116 \times \frac{1}{2}\right)$ .082"

aft leak @ 90 = $\frac{779}{2:30.44}$

leak aft = $\frac{423}{2:32.6}$

Fwd glass leak Total $\frac{380}{2047}$

Notes:

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